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A **Staff Report** *by the Straight Dope Science Advisory Board*

Why do we have so many temperature scales?

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Dear Straight Dope:

I have heard of five temperature measurements: Celsius (centigrade), Fahrenheit, Kelvin, Rankine, and Réaumur. How did so many scales arise? I know certain ones are goods for certain things (i.e., 0 Celsius is when water freezes, 0 Kelvin is absolute zero, etc.). But why are there so many, how did they arise, and can't you use one of them for all temperature purposes? --Josh G., Louisville, Kentucky

Guest contributor hibernicus replies:

You haven't heard the half of it. In addition to the Réaumur scale, which you mentioned, the roll-call of now-obsolete temperature scales includes the Newton, Rømer, Delisle, Leyden, Dalton, Wedgewood, Hales, Ducrest, Edinburgh and Florentine scales. In the 18th century, it was common to have up to four temperature scales (in one example, Newton, De Lisle, Réaumur and Fahrenheit) inscribed on the backing board of a thermometer.

Today, the only scales in everyday use are the Celsius and Fahrenheit scales, and (mainly for scientists and engineers) the Kelvin and Rankine scales. Réaumur may be familiar to readers of 19th-century Russian and French novels; the others are largely forgotten.

This story, of an unchecked proliferation of measurement units being pruned down to a few survivors, is not unique to temperature scales. I have a copy of an 18th century map of Switzerland which has seven distance scales, namely "Geometric or Italian miles," "Standard French Leagues," "Leagues of one hour's walk," "Standard German Leagues," "Short Swiss Leagues," "Standard Swiss Leagues," and "Long Swiss Leagues." I've seen as many as 13 scales on a single map, ranging from ancient Roman miles to Prussian wersts. Nowadays, we generally only need two scales, as distances over land are reckoned in either statute miles or kilometers.

While the various distance units had their origins in local custom in an age before easy communications, temperature scales differed for a more fundamental reason. Each of the early researchers effectively defined temperature according to the thermometric properties of his homemade measurement apparatus rather than in terms of the fundamental physical property we call thermodynamic temperature, which cannot be measured directly.

Among the earliest quantitative temperature scales was that developed in 1692 by Danish astronomer Ole (or Olef or Olaus) Rømer, who had earlier made measurements of the speed of light and developed a standard system of measures for the Danish realm based on the Rhineland foot. He noticed that in summer, his pendulum clock ran slower, and the graduations inscribed on his astronomical instruments were larger than in winter, making it impossible to carry out accurate measurements throughout the year. In order to compensate for this effect, he needed to quantify the thermal expansion of different materials, and to do this, he needed to be able to measure temperature.

In the 17th and 18th centuries, the state of the art temperature measurement device was the liquid-in-glass thermometer, a device consisting of a vertical glass tube connected to a closed reservoir or bulb filled with liquid, similar in principle to mercury thermometers except larger. Water is poorly suited for this purpose (one obvious problem: it freezes at a relatively warm temperature), so Rømer used "*spiritus vini* [approx 40% alcohol], colored with saffron" in an 18-inch long glass tube of constant cross-section. Isaac Newton, working on the problem at around the same time, used linseed oil instead of alcohol as a thermometric fluid.

To "fix" a temperature scale it's necessary to identify easily reproducible reference points, or "fiduciary points." Newton chose the temperature of melting snow and the temperature of boiling water, and marked off the interval into 33 or 34 "degrees," each corresponding to a certain height of oil in the tube.

Rømer at first used the same reference points, extending his scale to temperatures below freezing, with freezing point defined as 7.5 Rø and boiling point as 60 Rø. He later amended his standard for practical reasons so that the reference temperatures were ice water and "blood-warm" (i.e., human body temperature), which he defined as 22.5 Rø. From this we can deduce that on average, one degree Newton is equal to 100/33 C and 1 Rø is equal to approximately 1.9 C.

The Rømer scale was further developed by his successor Horrebow, to take account of the colder temperatures encountered in Iceland and Greenland, and by Daniel Gabriel Fahrenheit, whose modified scale remains in use to this day in the USA and Jamaica.

Already a talented glassmaker as a young man of 22, Fahrenheit traveled from Danzig to Copenhagen in 1708 to learn thermometry from Rømer (as well as to escape from his angry parents, who wanted to have him deported to the Dutch West Indies for borrowing money in their name). Later, Fahrenheit, declaring a dislike of ""inconvenient and awkward fractions," decided to subdivide Rømer's degrees to allow for the measurement of finer temperature intervals, and so he divided each degree Rømer into 4 degrees Fahrenheit. He then tweaked the numbers so that the melting point of snow was 32 degrees and the temperature "in the mouth or under the armpit of a living man in good health" represented the 96th degree on his scale. See Cecil's column on the subject for more detail.

Fahrenheit added a further fixed reference point: the temperature of an equilibrium mixture of ice and salt-saturated water, which he defined as the zero point of his scale. Unfortunately, the use of three reference points added ambiguity rather than precision--the value of a degree varies by over 8% depending on which two of his reference points you choose. (Yet another version, given by Hutton, is that Fahrenheit ascribed the value of 600 degrees to the boiling point of mercury--it's actually 674 F in the modern Fahrenheit scale).

After Fahrenheit's death, human body temperature was considered insufficiently constant to define a temperature scale, so his scale was jiggered to give it two reference points once again. This resulted in the current numerically unwieldy standard, with the freezing point of water defined as 32 F and the boiling point (at standard atmospheric pressure) defined as 212 F.

Fahrenheit also realized that alcohol was unsuitable for precise and repeatable temperature measurements. In 1714, he adopted mercury, which proved an excellent alternative--its co-efficient of thermal expansion is highly linear, it doesn't contain dissolved air, and its composition is guaranteed from one batch to the next, unlike the alcohol of the time. It's also much less sensitive to temperature change than alcohol, but you can't have everything.

Although the use of mercury had originally been suggested by Edmond Halley, the use of mercury thermometers graduated in degrees Fahrenheit became so widespread that the mercury thermometer came to be known as "Fahrenheit's thermometer," and the popularity and longevity of the Fahrenheit scale were assured.

René Antoine Ferchault de Réaumur's scale was developed in 1732, using a thermometer based on a particular mixture of alcohol and water. He also chose as reference points the freezing and boiling points of water, to which he assigned the values 0 R and 80 R respectively. 1 R is therefore equivalent to 1.25K. This scale was officially adopted throughout Europe except for Britain and Scandinavia, but beginning with the adoption of the centigrade scale by the French revolutionary government in 1794 it gradually declined in popularity, finally falling into disuse sometime in the 20th century.

The scale of Joseph DeLisle (modified by Weitbrecht in 1738) was an inverse scale, with the boiling point of water set at 0 and the freezing point at 150 degrees. It remained popular in Russia for a century or so. One degree DeLisle is equivalent to -2/3K.

In 1742, a Swedish astronomer named Anders Celsius proposed a centigrade scale, which uses the same reference points as the Fahrenheit scale, but divided for convenience into 100 degrees. (Originally, this scale too was inverted, with the ice point being 100 C and the steam point 0 C, but this was soon corrected to the more sensible system in use today.) The centigrade scale became popular first in Sweden and France (where it co-existed with the Réaumur scale) and later throughout most of the world. In 1948 this scale was renamed Celsius in honor of its creator.

As for whether just one temperature scale can be used for all purposes, in principle the answer is yes, provided it is an absolute scale (i.e., one whose zero point is the absolute zero of thermodynamic temperature). Certain physical relationships (such as the equivalence of heat and work, rates of chemical reactions, the ideal gas equations of state, the kinetic theory of gases, and the laws governing heat transfer) depend on multiplying or dividing temperatures. You won't get correct answers if you use a scale with an arbitrary zero point. Therefore around 1860, two absolute temperature scales were developed: the Rankine scale, based on the Fahrenheit degree, and the Kelvin scale, based on the centigrade degree. Note that the SI unit of temperature is called the "kelvin" (not "degree kelvin"). The freezing point of water is 273.15K and 491.67Ra.

Unfortunately, not only do different temperature scales give different numerical readings (because of the arbitrary choice of constant of proportionality by each researcher), but the use of different standard instruments results in different definitions of temperature itself. The relationship between volume and temperature is different for linseed oil, alcohol and mercury. In fact the same is true for any thermometric property available to us, such as electrical resistance or gas pressure. The definition of temperature therefore depends on the instrument chosen as a standard, and two different instruments that read the same temperature at the reference points will in general not agree at other temperatures.

In an attempt to free the modern science of thermodynamics from the ghosts of 18th century instruments, the Kelvin (and hence, Celsius) temperature scale was redefined in 1954 in terms of the interval between absolute zero and a single fixed reference point (namely, the triple point of water, set at 273.16K, or 0.01 C). The thermodynamic temperature of any system could in theory be established using a constant-volume ideal gas thermometer. No longer would the properties of any real substance determine the temperature. This means that the boiling point of water is no longer set at 100 C by definition (in fact the current best available figure is 99.974 C), and so strictly speaking the modern Celsius scale is no longer a "centigrade" scale.

In practical terms, unfortunately, there is no such thing as an ideal gas, and therefore no such thing as an ideal gas thermometer. A real-world temperature scale will therefore necessarily be considerably less elegant. The standard temperature scale now in use is called the "International Temperature Scale 1990" (ITS-90), the result of years of work at the UK's National Physical Laboratory and elsewhere. This uses no less than 16 reference points, from the triple point of hydrogen (defined as 13.8033K), through the melting point of gallium (302.9146K) to the freezing point of copper (1357.77K). Like all its predecessors, it is not perfect; in fact it is an inelegant kludge, consisting of 5 discontinuous and overlapping ranges based on three different types of measurement device, and does not yet extend to temperatures below 0.65K. The ITS has been derisively referred to as a "rubber scale," because it stretches or shrinks as improved measurement data becomes available. Nonetheless, it is, for the moment, adequate for our need and ability to measure temperature, and it's the best we've got.

Further reading:

Charles Hutton, *Mathematical and Philosophical Dictionary* (1795) has an excellent summary of the early temperature scales and methods under the entry "Thermometer," available online at archimedes.mpiwg-berlin.mpg.de/c gi-bin/toc/toc.cgi?page=1311;dir=hutto_dicti_078_en_1795;step=textonly.

Erling Poulsen, *Early Danish Thermometers: The Thermometers of Ole Rømer* (www.rundetaarn.dk/engel sk/observatorium/tempeng.htm)

National Physical Laboratory's Temperature FAQ at www.npl.co.uk/thermal/faq_index.html

See also:

An image of a beautiful old 4-scale thermometer at www.scienceandsociety.co.uk/results.asp?image=10413117&wwwflag=& imagepos=1

A diagram from 1776 comparing 15 temperature scales at http://www.scienceand society.co.uk/results.asp?image=10313289

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--Guest contributor hibernicus
Straight Dope Science Advisory Board

[Comment on this answer.]

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